

# Hadronic Decays and Baryon Structure

T. Melde, W. Plessas, and B. Sengl

Theoretical Physics, Institute for Physics, University of Graz,  
Universitätsplatz 5, A-8010 Graz, Austria

## Abstract

Relativistic constituent quark models generally describe three-quark systems with particular interactions. The corresponding invariant mass eigenvalue spectra and pertinent eigenstates should exhibit the multiplet structure anticipated for baryon resonances. Taking into account the flavour content, spin structure, and spatial distribution of the baryon wave functions together with mass relations of the eigenvalues and decay properties of the eigenstates, we can link the theoretical mass eigenstates with the experimentally measured resonances. The resulting classification of baryon resonances differs in some respects from the one suggested by the Particle Data Group. With regard to the hadronic decay widths of light and strange baryon resonances a consistent picture emerges only, if the classification includes two-star resonances.

## Introduction

Constituent quark models (CQMs) for light and strange baryons have seen a number of important new developments over the last few years. Generally, CQMs are specified by a confining interaction and an interaction responsible for the hyperfine splitting of the baryon spectra. There has been a number of different implementations of hyperfine (and confining) interactions, and some prominent models are based on one-gluon-exchange (OGE) [1], instanton-induced (II) [2, 3], and Goldstone-boson-exchange (GBE) dynamics [4, 5].

Recently, we have presented relativistic calculations of  $\pi$  and  $\eta$  decay widths of  $N$  and  $\Delta$  resonances within the point-form spectator model (PFSM), and it has been seen that the experimental data are systematically underestimated [6]. Similar characteristics of these decay widths have been found by the Bonn group following a completely different relativistic approach, namely with the II CQM in the framework of the Bethe-Salpeter equation [7, 8]. Previous studies of mesonic baryon decays along CQMs essentially employed nonrelativistic or relativised methods [9, 10, 11, 12, 13, 14, 15]. Our investigations of hadronic decays within the point form have now been extended to the nonstrange decays of strange resonances [16]. The corresponding decay widths exhibit similar characteristics as the ones in the light sector [6]. A specific interpretation has been reached with regard to the three  $\frac{1}{2}^-$   $\Sigma$  levels produced by CQMs (below 2 GeV): Only the third excitation (in the GBE CQM) should be identified with the measured  $\Sigma(1750)$  resonance.

## Classification in Flavour Multiplets

Motivated by the consistent picture that arose from the PFSM results for hadronic decay widths we undertook a classification of the mass-operator eigenstates into flavour multiplets according to their most congruent behaviour of spatial densities, spin as well

Table 1: Suggested classification of experimentally seen baryons. The last column denotes the multiplet number according to Guzey and Polyakov [17]. The superscripts denote the percentages of octet, singlet, and decuplet flavour contributions in the respective states (specifically in case of the GBE CQM).

$(LS)J^P$					#
Octets					
$(0\frac{1}{2})\frac{1}{2}^+$	$N(939)^{100}$	$\Lambda(1116)^{100}$	$\Sigma(1193)^{100}$	$\Xi(1318)^{100}$	1
$(0\frac{1}{2})\frac{1}{2}^+$	$N(1440)^{100}$	$\Lambda(1600)^{96}$	$\Sigma(1660)^{100}$	<b><math>\Xi(1690)^{100}</math></b>	3
$(0\frac{1}{2})\frac{1}{2}^+$	$N(1710)^{100}$		<b><math>\Sigma(1880)^{99}</math></b>		4
$(1\frac{1}{2})\frac{1}{2}^-$	$N(1535)^{100}$	$\Lambda(1670)^{72}$	<b><math>\Sigma(1560)^{94}</math></b>		9
$(1\frac{3}{2})\frac{1}{2}^-$	$N(1650)^{100}$	$\Lambda(1800)^{100}$	<b><math>\Sigma(1620)^{100}</math></b>		14
$(1\frac{1}{2})\frac{3}{2}^-$	$N(1520)^{100}$	$\Lambda(1690)^{72}$	$\Sigma(1670)^{94}$	$\Xi(1820)^{97}$	8
$(1\frac{3}{2})\frac{3}{2}^-$	$N(1700)^{100}$		$\Sigma(1940)^{100}$		11
$(1\frac{3}{2})\frac{5}{2}^-$	$N(1675)^{100}$	$\Lambda(1830)^{100}$	$\Sigma(1775)^{100}$	<b><math>\Xi(1950)^{100}</math></b>	12
Singlets					
$(0\frac{1}{2})\frac{1}{2}^+$		<b><math>\Lambda(1810)^{92}</math></b>			4
$(1\frac{1}{2})\frac{1}{2}^-$		$\Lambda(1405)^{71}$			6
$(1\frac{1}{2})\frac{3}{2}^-$		$\Lambda(1520)^{71}$			7
Decuplets					
$(0\frac{3}{2})\frac{3}{2}^+$	$\Delta(1232)^{100}$	$\Omega(1672)^{100}$	$\Sigma(1385)^{100}$	$\Xi(1530)^{100}$	2
$(0\frac{3}{2})\frac{3}{2}^+$	$\Delta(1600)^{100}$		<b><math>\Sigma(1690)^{99}</math></b>		5
$(1\frac{1}{2})\frac{1}{2}^-$	$\Delta(1620)^{100}$		<b><math>\Sigma(1750)^{94}</math></b>		10
$(1\frac{1}{2})\frac{3}{2}^-$	$\Delta(1700)^{100}$				13

as flavour content, mass relations, and decay properties. A natural pattern of flavour multiplets emerges that comprises also experimentally less well established (i.e., two-star) resonances. The resulting multiplets are summarized in Table 1. In the first column the total spin and parity  $J^P$  of the flavour multiplet members are given as well as the total orbital angular momenta  $L$  and total spins  $S$  specifying their wave functions in the rest frame. The bold-face entries denote states where our classification differs from the one by the PDG [18], and the last column refers to the multiplet number according to the classification of Guzey and Polyakov [17]. This classification is nearly identical to ours. The only exception is the  $\Lambda(1810)$ , which turns out to be a flavour singlet (with a percentage of 92%) rather than a flavour octet.

The PDG suggests a classification of baryons without consideration of one- and two-star resonances [18]. The proposed scheme closely resembles the one by Samios et al. [19] postulated already in 1974, when many of the resonances known today have not yet been confirmed. In the context of modern relativistic CQMs one learns that also less well established resonances of two-star status should be included into a classification of flavour multiplets. A prominent example is the  $\Sigma(1750)$ , which is to be identified only with the

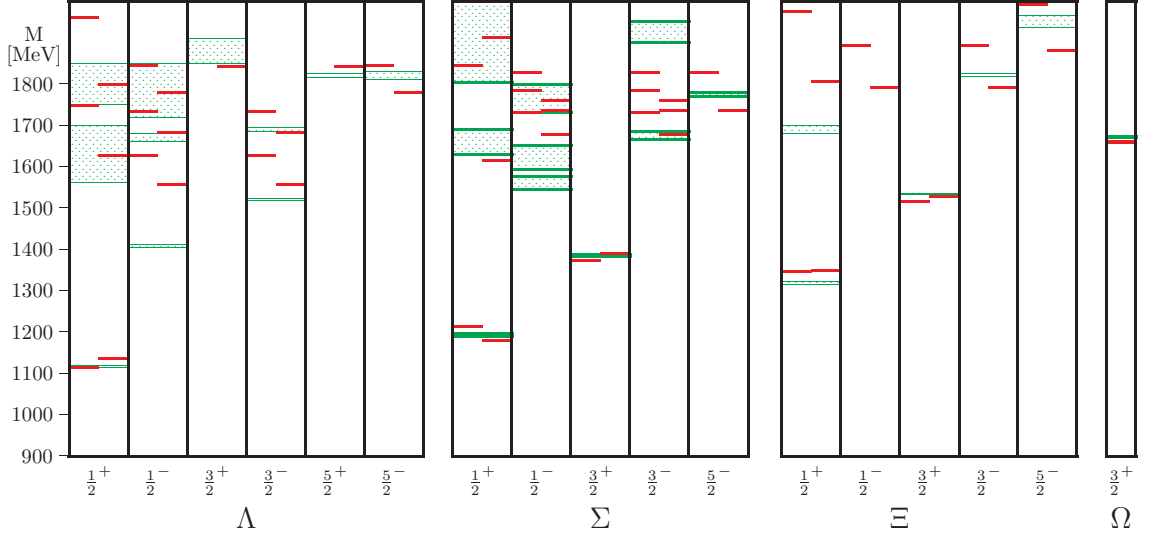


Figure 1:  $\Lambda$ ,  $\Sigma$ ,  $\Xi$ , and  $\Omega$  spectra for OGE (left) and GBE (right) CQMs.

third  $\frac{1}{2}^-$  excitation in CQMs and turns out to be in a flavour decuplet.

The octet states in Table 1 have a pure or very predominant octet flavour content, with the notable exceptions of the  $\Lambda(1670)$  and  $\Lambda(1690)$ ; the latter couple strongly to singlet states. The state  $\Lambda(1810)$  is identified as a (nearly pure) singlet state in concordance with a recent large- $N_c$  study [20]. The other two singlets exhibit considerable admixtures of octet contributions, congruent with the singlet contributions of their partners in the octet multiplets. It should also be noted that the classification of the  $\Xi(1950)$  as  $J^P = \frac{5}{2}^-$  is different from a recent one by Zhou and Ma [21], who classified it as a  $J^P = \frac{3}{2}^-$ .

In Fig. 1 we show all the experimental resonance states (shadowed boxes) employed for the classification of the mass eigenstates produced by the GBE and OGE CQMs (horizontal lines). Specifically in the  $\Sigma$  excitation spectrum with  $J^P = \frac{1}{2}^-$  a natural explanation of the states is found, if in addition to the  $\Sigma(1750)$  also the two lower lying states are included, which are seen in experiment as two-star resonances. It is interesting to note that the ordering of the three  $\Sigma$  states with  $J^P = \frac{1}{2}^-$  is different in the two CQMs, namely octet-decuplet-octet for the OGE and octet-octet-decuplet for the GBE. Only in the  $\Sigma$  spectrum with  $J^P = \frac{3}{2}^-$  and the  $\Xi$  spectrum with  $J^P = \frac{1}{2}^-$  we still observe more theoretical states than experimentally seen resonances. However, at least in case of the  $\Sigma$  the PDG expects a resonance in the relevant mass range.

## Summary

We have investigated the properties of the light and strange baryons obtained with the relativistic OGE and GBE CQMs. It has been found that the CQMs provide a high degree of systematics with regard to the spectroscopy: The invariant mass eigenstates yield a consistent pattern of flavour multiplets. In particular, the  $\Sigma(1750)$  is identified as a flavour decuplet. Additional two-star resonances can be interpreted consistently. A new classification is reached differing in some respects from the one by the PDG [18].

On the other hand, one faces difficulties in the description of baryon reactions. In particular, the predictions of covariant decay widths along the PFSM cannot explain all

of the experimental results. Further relativistic studies are necessary. In particular, investigations on the intricacies of the PFSM construction [22] might be of further relevance. For a more refined approach the inclusion of explicit mesonic degrees of freedom appears mandatory. Investigative coupled-channel calculations in a Poincaré-invariant quantum-mechanical framework have already been performed in the meson sector [23, 24]. However, the complexity of this approach still prevents the application to baryons. For including mesonic degrees of freedom in the description of baryons, a promising first step would be to take into account appropriate contributions (similar to the ones derived in Ref. [25]) directly on the baryon-meson level.

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